

**PORTABLE GAS FRACTIONALIZATION SYSTEM**Background of the InventionField of the Invention

[0001] This invention relates generally to a portable gas fractionalization system, more particularly, to a compact oxygen concentrator that is suitable for both in-home and ambulatory use so as to provide users greater ease of mobility.

Description of the Related Art

[0002] Patients who suffer from respiratory ailments such as Chronic Obstructive Pulmonary Diseases (COPD) often require prescribed doses of supplemental oxygen to increase the oxygen level in their blood. Supplemental oxygen is commonly supplied to the patients in metal cylinders containing compressed oxygen gas or liquid oxygen. Each cylinder contains only a finite amount of oxygen that typically lasts only a few hours. Thus, patients usually cannot leave home for any length of time unless they carry with them additional cylinders, which can be heavy and cumbersome. Patients who wish to travel often have to make arrangements with medical equipment providers to arrange for an exchange of cylinders at their destination or along the route, the inconvenience of which discourages many from taking extended trips away from home.

[0003] Supplemental oxygen can also be supplied by oxygen concentrators that produce oxygen concentrated air on a constant basis by filtering ambient air through a molecular sieve bed. While oxygen concentrators are effective at continual production of oxygen, they are typically large electrically powered, stationary units that generate high levels of noise, in the range of 50-55 dB, which presents a constant source of noise pollution. Moreover, the units are too heavy to be easily transported for ambulatory use as they typically weigh between 35 to 55 lbs. Patients who use oxygen concentrators are thus tethered to the stationary machines and inhibited in their ability to lead an active life. While portable oxygen concentrators have been developed to provide patients with greater mobility, the currently commercially available portable concentrators do not necessarily provide patients with the ease of mobility that they desire. The portable concentrators tend to

generate as much noise as the stationary units and thus cannot be used at places such as the theater or library where such noise is prohibited. Moreover, the present portable concentrators have very short battery life, typically less than one hour, and thus cannot be used continuously for any length of time without an external power source.

[0004] From the foregoing, it will be appreciated that there is a need for an apparatus and method that effectively provide supplemental oxygen to patients for both in-home and ambulatory use. To this end, there is a particular need for a portable oxygen concentrator that is lightweight, quiet, and can supply oxygen continuously for an extended period without requiring an external power source.

#### Summary of the Invention

[0005] In one aspect, the preferred embodiments of the present invention provide a portable gas fractionalization apparatus comprising a compressor which compresses a gas, such as air, to provide a feed gas; plural adsorbent beds which receive said feed gas and output a purified gas and a waste gas; a battery which supplies power to said compressor; and a housing which comprises an ambient air inlet, an ambient air outlet, and plural compartments. Preferably, a first of the compartments contains the adsorbent beds and a second of the compartments contains the compressor, wherein the compartments significantly inhibit migration of thermal energy from the second compartment to the first compartment. In one embodiment, the apparatus further comprises an air circulation fan which draws air through the inlet into the first compartment, and through the first compartment into the second compartment, the air being exhausted through the outlet. Preferably, the fan is positioned directly above the compressor and produces an air stream directly against the compressor.

[0006] In one embodiment, the housing further comprises a circuitous air passageway having an upstream portion and a downstream portion through which the air is directed to flow. The upstream portion is preferably positioned adjacent the first compartment and the downstream portion is positioned adjacent the second compartment. Preferably, air in the downstream portion is substantially inhibited from flowing into the upstream portion. In one embodiment, the first compartment further contains heat sensitive

components including a plurality of valves interconnected to the adsorbent beds and a circuit board having control circuitry which governs the operation of the valves. In another embodiment, the apparatus further comprises a plurality of sound absorbing baffles positioned along at least a portion of the air passageway.

[0007] In a second aspect, the preferred embodiments of the present invention provide a portable gas fractionalization apparatus which includes a housing comprised of a chassis and a shell. The apparatus further includes a plurality of components mounted on and structurally supported by the chassis. Preferably, the shell covers the components and is removable from the chassis without removing the components. In one embodiment, the shell has a plurality of sidewalls, wherein at least one sidewall has a concave or convex section that provides curvature to the sidewall so as to reduce coupling of sound or vibration energy generated by components in the housing. In another embodiment, the shell has an opening adapted to receive a filter which filters fluid output from the apparatus wherein the filter is accessible from the exterior of the shell. Moreover, the chassis preferably comprises a plurality of integral structures adapted to receive and support the components, such as an integral compressor mount, an integral battery slot, and at least one integral gas flow passageway. Preferably, the chassis provides an intermediary vibration isolation between the components and the shell of the housing. In certain embodiments, the housing further includes a hatch that is removably attached to the shell to provide access to one or more components therein.

[0008] In a third aspect, the preferred embodiments of the present invention provide a portable gas fractionalization apparatus comprising a compressor which produces a feed gas; plural adsorbent beds connected to receive the feed gas and produce a purified gas and a waste gas from the feed gas; a battery; and a conduit connected to deliver the waste gas to the battery to cool the battery. In one embodiment, the waste gas comprises a nitrogen rich gas. In another embodiment, the battery is positioned in a battery compartment such that the conduit delivers waste gas to a space between the battery and the battery compartment. Preferably, the battery compartment is comprised of a thermal sleeve positioned around the battery.

[0009] In a fourth aspect, the preferred embodiments of the present invention provide a method of producing oxygen. The method comprises providing an oxygen concentrator having an air compressor which supplies compressed air to a PSA unit comprising plural adsorbent beds and a plurality of valves which control fluid flow to and from the beds; generating an air flow through the concentrator by inputting air through an inlet and outputting the air through an outlet, such that the air flows along a flow path through the concentrator; and exposing the valves to an upstream portion of the flow path and exposing the air compressor to a downstream portion of the flow path, such that the valves are substantially isolated from air that flows through the downstream portion of the flow path. Preferably, the air flow is generated using an air circulation fan to produce an air stream directly against the air compressor. In one embodiment, the method further comprises directing the air flow to flow along a circuitous flow path through the concentrator. Preferably, the air in the downstream portion of the flow path is substantially inhibited from circulating back into the upstream portion. In one embodiment, the method further comprises providing a plurality of sound baffles along at least a portion of the air flow path to reduce noise generated by the air flow and guide the air flow along the flow path.

#### Brief Description of the Drawings

[0010] FIGURE 1 is a block diagram of a portable gas fractionalization system of one preferred embodiment of the present invention;

[0011] FIGURE 2 is a perspective view of a portable gas fractionalization apparatus of another preferred embodiment, which is shown in the form of an oxygen concentrator;

[0012] FIGURE 3 is a perspective view of the apparatus of Figure 2 as seen with the shell removed;

[0013] FIGURE 4 is a perspective view of the chassis of the apparatus of Figure 2;

[0014] FIGURE 5 is a perspective view of the components inside the first compartment of the apparatus of Figure 2, showing a PSA unit;

[0015] FIGURE 6 is a schematic illustration of an adsorbent bed column of the PSA unit of Figure 5;

[0016] FIGURES 7A and 7B are schematic diagrams of gas flow to and from the adsorbent bed column of Figure 6;

[0017] FIGURE 8 is a detailed view of the integrated manifold of the PSA unit of Figure 5;

[0018] FIGURE 9 is a schematic illustration of a water trap system incorporated in the integrated manifold of Figure 8;

[0019] FIGURE 10 is a schematic illustration of a piloted valve system incorporated in the integrated manifold of Figure 8;

[0020] FIGURE 11 is a perspective view of the components inside the second compartment of the apparatus of Figure 2, showing a compressor system;

[0021] FIGURE 12 is a perspective view of a vibration damping member incorporated in the compressor system of Figure 11;

[0022] FIGURE 13 is a perspective view of the components assembled in the housing of the apparatus of Figure 2;

[0023] FIGURE 14 is a schematic diagram of a directed ambient air flow through the housing of the apparatus of Figure 2, illustrating a thermal management system of one preferred embodiment;

[0024] FIGURE 15 is a schematic diagram of a gas flow through the components of the apparatus of Figure 2;

[0025] FIGURE 16A is perspective view of the apparatus of Figure 2, showing an in-line filter integrated in the shell of the apparatus;

[0026] FIGURE 16B is a detailed view of the in-line filter of Figure 16B;

[0027] FIGURE 16C is a perspective view of the apparatus of Figure 2, showing a removable hatch;

[0028] FIGURE 17 is a schematic illustration of a satellite conserver used in conjunction with the apparatus of Figure 2;

[0029] FIGURES 18A and 18B are schematic illustrations of a mobility cart used in conjunction with the apparatus of Figure 2 for transporting the apparatus .

### Detailed Description of Preferred Embodiments

[0030] Figure 1 schematically illustrates a portable gas fractionalization system 100 of one preferred embodiment of the present invention. As shown in Figure 1, the system 100 generally comprises an intake 102 through which ambient air is drawn into the system, a filter 104 for removing particulate from the intake air, a compressor assembly 106 for pressurizing the intake air to provide a feed gas, a pressure swing adsorption (PSA) unit 108 which receives and processes the feed gas to produce a product gas having a higher oxygen content than the ambient air, and a gas delivery system 110 for delivering the product gas to a patient.

[0031] Ambient air is drawn through the intake 102 at a relatively low flow rate, preferably no greater than about 15 standard liters per minute (slpm), so as to reduce noise due to airflow through the system. The system 100 further includes a fan 112 that produces an air stream across the compressor assembly 106 also preferably at a relatively low flow rate so as to provide cooling for the compressor assembly 106 without generating excessive noise.

[0032] As also shown in Figure 1, the compressor assembly 106 includes a compressor 114 and an heat exchanger 116. The compressor 114 is preferably a non-reciprocating compressor, more preferably a scroll compressor described in U.S. Patent Nos. 5,759,020 and 5,632,612, which are hereby incorporated by reference in their entirety. It is generally understood that a scroll compressor operates by moving a plate such that it orbits in a single plane relative to a fixed plate. Thus, the use of a scroll compressor advantageously eliminates reciprocating motion that tends to generate the excessive noise and vibration associated with many conventional piston compressors. In one embodiment, the scroll compressor 114 delivers an air flow of between about 4 to 9 slpm at a pressure of about 35 psia, while generating a noise level of less than about 35 dB external to the compressor. The scroll compressor 114 does not require lubricating oil and thus operates in a substantially oil-free environment, which advantageously reduces the likelihood of introducing oil contaminants into the compressed air. As Figure 1 further shows, the compressor 114 works in conjunction with the heat exchanger 116 to provide cooled feed gas to the PSA unit 108. In one embodiment, the heat exchanger 116 has a large thermally conductive surface that is

in direct contact with the air stream produced by the fan 112 such that pressurized air traveling through the heat exchanger 116 can be cooled to a temperature close to ambient prior to being supplied to the PSA unit 108.

[0033] The PSA unit 108 is configured to operate in accordance with a pressure swing adsorption (PSA) cycle to produce an oxygen enriched product gas from the feed gas. The general operating principles of PSA cycles are known and commonly used to selectively remove one or more components of a gas in various gas fractionalization devices such as oxygen concentrators. A typical PSA cycle entails cycling a valve system connected to at least two adsorbent beds such that a pressurized feed gas is sequentially directed into each adsorbent bed for selective adsorption of a component of the gas while waste gas from previous cycles is simultaneously purged from the adsorbent bed(s) that are not performing adsorption. Product gas with a higher concentration of the un-adsorbed component(s) is collected for use. Additional background information on PSA technology is described in U.S. Patent No. 5,226,933, which is hereby incorporated by reference.

[0034] As shown in Figure 1, the PSA unit 108 of a preferred embodiment includes two adsorbent beds 118a, 118b, each containing an adsorbent material that is selective toward nitrogen, and a plurality of valves 120a-j connected thereto for directing gas in and out of the beds 118a, 118b. As will be described in greater detail below, the valves 120a-j preferably operate in accordance with a novel PSA cycle which comprises a six step/two bed process that includes a pressure equalization step in which a portion of the effluent product gas from one bed is diverted to pressurize another bed in order to improve product recovery and reduce power consumption. One preferred embodiment of the PSA cycle comprises the following steps:

*Step 1: Pressurize-Adsorbent Bed 118a / Production-Adsorbent Bed 118b*

- pressurizing adsorbent bed 118a by directing feed gas into adsorbent bed 118a in the co-current direction at a feed pressure of about 35 psia while simultaneously diverting oxygen enriched product gas of higher pressure from adsorbent bed 118b into adsorbent bed 118a in the counter-current direction until pressures of the two beds 118a, 118b are substantially equalized;

- releasing product gas from adsorbent bed 118b to a storage vessel 124 while stopping the flow of feed gas from entering adsorbent bed 118b;

*Step 2: Feed-Adsorbent Bed 118a / Blowdown-Adsorbent Bed 118b*

- feeding adsorbent bed 118a with feed gas at a rate of about 4-8.5 slpm at a feed pressure of about 35 psia;
- counter-currently releasing nitrogen enriched waste gas from adsorbent bed 118b to an exhaust muffler 122;

*Step 3: Feed and Production-Adsorbent Bed 118a / Purge-Adsorbent Bed 118b*

- releasing product gas from adsorbent bed 118a to the storage vessel 124 while continuing to feed adsorbent bed 118a with feed gas at a rate of about 4-8.5 slpm. at a feed pressure of about 35 psia;
- purging adsorbent bed 118b by releasing product gas from the storage vessel 124 to adsorbent bed 118b while continuing to counter-currently release waste gas from adsorbent bed 118b to the exhaust muffler 122;

*Step 4: Production-Adsorbent Bed 118a / Pressurize-Adsorbent Bed 118b*

- continuing to release product gas from adsorbent bed 118a to the storage vessel 124 while stopping the flow of feed gas from entering adsorbent bed 118a;
- pressurizing adsorbent bed 118b by directing feed gas into adsorbent bed 118b in the co-current direction at a feed pressure of about 35 psia while simultaneously diverting product gas of higher pressure from adsorbent bed 118a into adsorbent bed 118b in the counter-current direction until pressures of the two beds 118a, 118b are substantially equalized;

*Step 5: Blowdown-Adsorbent Bed 118a / Feed-Adsorbent Bed 118b*

- counter-currently releasing waste gas from adsorbent bed 118a to the exhaust muffler 122;
- feeding adsorbent bed 118b with feed gas at a rate of about 4-8.5 slpm at a feed pressure of about 35 psia;

*Step 6: Purge-Adsorbent Bed 118a / Feed and Production-Adsorbent Bed 118b*



- releasing product gas from adsorbent bed 118b to the storage vessel 124 while continuing to feed adsorbent bed 118b with feed gas at a rate of about 4-8.5 slpm at a feed pressure of about 35 psia;
- purging adsorbent bed 118a by releasing product gas from the storage vessel 124 to adsorbent bed 118a while continuing to counter-currently release waste gas from adsorbent bed 118a to the exhaust muffler 122;

[0035] The PSA cycle described above advantageously includes one or more pressure equalization steps (steps 1 and 4) in which already pressurized product gas is released from one adsorbent bed to provide initial pressurization for another adsorbent bed until the two beds have reached substantially the same pressure. The pressure equalization step leads to increased product recovery and lower power consumption because it captures the expansion energy in the product gas and uses it to pressurize other adsorbent beds, which in turn reduces the amount of power and feed gas required to pressurize each bed. In one embodiment, the two-bed PSA unit shown in Figure 1 operating in accordance with the above-described six-step/two-bed PSA cycle is capable of producing oxygen having a purity of at least about 87%, preferably between about 87%-93%, with greater than about 31% recovery of oxygen from feed gas, more preferably greater than about 38% recovery. In operation, the valves 120a-j of the PSA unit 108 are controlled in a known manner to open and close for predetermined time periods in accordance with the above described PSA steps. Additionally, the valves 120a-j are preferably positioned upstream of the air stream produced by the fan 112 across the compressor assembly 106 so as to not expose the valves 120a-j to portions of the air stream that are heated by the compressor assembly 106. In other embodiments, the system may utilize a vacuum swing adsorption (VSA) unit or a vacuum-pressure swing adsorption (VPSA) unit to produce the oxygen rich product gas.

[0036] As Figure 1 further shows, the product gas produced by the PSA unit 108 is delivered to a patient via the product gas delivery system 110. The product gas delivery system 110 generally includes an oxygen sensor 126 for monitoring the oxygen content of the product gas exiting the storage vessel 124, a delivery valve 128 for metering the product gas to the patient, an in-line filter 130 for removing fine particulate in the product gas immediately prior to delivery to the patient, a conserver device 132 that controls the amount

and frequency of product gas delivered based on the patient's breathing pattern. In certain embodiments, the product gas delivery system may also incorporate a unit that measures pressure within the storage vessel which in turn dictates the rate at which product gas is driven through the delivery valve. Preferably, product gas is delivered to the patient at a flow rate of about 0.15-0.75 slpm at about 90% oxygen content. In one embodiment, the system 100 also includes a microprocessor control 134 for collecting and recording data on system performance or patient usage pattern and an infrared port 136 for transmitting the data to a remote location.

[0037] Figure 2 illustrates a gas fractionalization apparatus 200 of the preferred embodiment, which is shown in the form of a portable oxygen concentrator. As illustrated in Figure 2, the apparatus 200 generally comprises a chassis 202 (see also Figure 3) and a shell 204 that together form a housing 206 in which various components are mounted. The chassis 202 is removably attached to a base 208 of the housing 206. The base 208 has a substantially planar exterior bottom surface adapted to rest against a support surface such as a table or floor. The shell 204 of the housing 206 further includes an upper wall 210 and side walls 212a-d, each having at least one convex and/or concave section that provides a curvature to the wall so as to reduce coupling of sound or vibration energy generated by the components in the housing. Such curvature is also effective to reduce constructive interference of the coupled energy within the walls. Accordingly, the lack of planar sections in the walls 210, 212a-d of the housing 206 that are conducive to vibration reduces noise induced by vibration. Moreover, the non-planar walls 210, 212a-d also serve to discourage users from setting the housing on its side or placing it in any orientation other than the upright as the components inside the housing are designed to operate optimally in the upright orientation, which will be described in greater detail below.

[0038] As shown in Figure 3, the components in the housing 206 are structurally supported by the chassis 202 and the chassis 202 is removably attached to the shell 204. As such, the components can be assembled outside the confines of the shell 204. Also, the shell can be conveniently removed to provide access for testing, repair, or maintenance of the components. Additionally, the housing 206 is preferably separated into two compartments 300, 302 by a partition 304. The partition 304 in conjunction with an air flow system to be

described in greater detail below significantly inhibits migration of thermal energy from the second compartment 302 to the first compartment 300. Preferably, heat sensitive components are placed in the first compartment 300 and heat generating components are mounted in the second compartment 302 so as to thermally isolate the heat sensitive components from the heat generating components for optimal system performance.

[0039] Figure 4 provides a detailed view of the chassis 202, as seen without the components. As shown in Figure 4, the chassis 202 contains a number of pre-formed structures configured to receive and support the different components in the housing. Three circular recess 400a-c are formed in a first base portion 402 of the chassis 202 for mating with a PSA unit. Three corresponding divots 404a-c are also formed in the first base portion 402 immediately adjacent each respective recess 400a-c. The divots 404a-c extend laterally into each respective recess 400a-c to direct gas flow in and out of the PSA unit in a manner to be described in greater detail below. As such, the chassis serves as a manifold of sorts for routing gases to and from the PSA unit. An annular compressor mount 406 extends upwardly from a second base portion 408 of the chassis 202 to provide an elevated mounting surface for a compressor assembly and define an opening 410 sufficiently large to receive a portion of the assembly. As will be described in greater detail, the compressor mount 406 is configured to support the compressor assembly in a manner such that transfer of vibrational energy from the compressor assembly to the housing is reduced. As also shown in Figure 4, an oblong slot 412 and a bail 414 are formed adjacent the compressor mount 406 for receiving and securing a battery. In one embodiment, electrical mating contacts are formed in the slot 412 for connecting the battery to operating circuitry. In one embodiment, a battery circuit is mounted on the bottom of the slot which can also contain a IRDA transmitter/receiver. Moreover, the chassis 202 can also be fit with notches to receive and support the bottom of the partition.

[0040] Preferably, at least some of the above-described structures of the chassis 202 are integrally formed via an injection molding process so as to ensure dimensional accuracy and reduce assembly time. These pre-formed structures in the chassis advantageously facilitate assembly of the components and help stabilize the components once they are assembled in the housing. In one embodiment, the chassis serves the function of

providing an intermediary vibration isolation to the compressor and motor. As shown in Figure 4, the chassis has bottom mounts or vibration isolation feet 407 that are configured to engage with the bottom of the shell. Preferably, screws are inserted through the bottom of the shell and into the bottom of the vibration feet 407. In another embodiment, the chassis further comprises an integrated muffler for exhaust gas. Preferably, a recess is formed below the battery slot in which felt or other porous material is placed. As will be described in greater detail below, an exhaust tube from the PSA unit is preferably ported directly into this recess and the felt serves to break up noise coming from the release of pressurized waste gas.

[0041] Figure 5 provides a detailed view of the components in the first compartment 300 of the housing 206. As shown in Figure 5, the first compartment 300 generally contains an air intake 502, an intake filter 504, and a PSA unit 506. The air intake 502 is an elongated tube coupled to the intake filter 504 and extending downwardly therefrom to receive intake air. The intake filter 504 comprises a cylindrical shaped filter that is preferably capable of removing particles greater than about 0.1 microns from the intake air with about 93% efficiency. Moreover, the shape, density, and material of the intake filter 504 can be selected to provide the filter with acoustic properties so that the filter can also serve as an intake muffler. As will be described in greater detail below, the intake filter 504 is in fluid communication with a compressor system and supplies the compressor system with filtered intake air. Both the air intake 502 and the intake filter 504 are preferably mounted in the first compartment 300 of the housing 206 so as to avoid drawing higher temperature air produced by components in the second compartment into the system.

[0042] As Figure 5 further shows, the PSA unit 506 generally includes a pair of adsorbent bed columns 508a, 508b, a product gas storage column 510, and an integrated manifold 512 for controlling fluid flow to and from the columns 508a-b, 510. Each adsorbent bed column 508a-b comprises an elongated housing containing a nitrogen-selective adsorbent material such as zeolite. The adsorbent bed columns 508a-b are adapted to remove nitrogen from intake air in a known manner in accordance with a PSA cycle so as to produce an oxygen rich product gas. The product gas storage column 510 comprises an elongated housing adapted to receive and store the oxygen rich product gas. In one embodiment, the product gas storage column 510 also contains an adsorbent material capable of holding a

higher molar density of the product gas than an equivalent gas filled chamber at equal pressure. As shown in Figure 5, all three columns 508a-b, 510 are mounted side by side in the housing 206. Preferably, the columns 508a-b, 510 have substantially the same length so that the integrated manifold 512 can be mounted horizontally on the upper end of the columns 508a-b, 510.

[0043] As will be described in greater detail below, the integrated manifold 512 contains a plurality of integrated flow passages formed in a single plane that permit fluid to flow to and from the columns 508a-b, 510. The integrated manifold 512 also has a plurality of solenoid valves 514 positioned in a single plane that control the flow of the fluid to and from the columns 508a-b, 510 during a PSA cycle. As shown in Figure 5, the integrated manifold 512 is mounted on the upper end of the columns 508a-b, 510 in a manner such that the integrated flow passages in the manifold are in fluid communication with openings in the upper end of each column. While the manifold 512 is positioned on only the upper end of the columns, gas flow from the manifold can enter the column housing through either the upper or lower end due to a novel single-ended column design to be described in greater detail below. In one embodiment, the valves 514 of the manifold 512 contain a plurality of contact pins 516 adapted for direct contact with a circuit board in a manner to be shown in greater detail below. A circuit board controlling the valves can be mounted directly on top of the manifold 512 without additional wires, which advantageously simplifies the assembly process and also allows for the construction of a more compact device.

[0044] In one embodiment, an oxygen sensor 518 is mounted on the integrated manifold 512 and ported directly into a product gas flow passage in the manifold 512. The oxygen sensor 518 is configured to measure the oxygen concentration in the product gas using a galvanic cell or other known devices. Mounting the oxygen sensor 518 directly on the integrated manifold 512 results in a more compact assembly as it eliminates the use of tubing and connectors that are typically required to interconnect the oxygen sensor to the PSA unit. Moreover, it also places the oxygen sensor 518 closer to the product gas stream, which is likely to improve the accuracy and response time of the sensor. In another embodiment, a breath detector 520 is also ported into the integrated manifold 512. The breath detector 520 generally comprises one pressure transducer that senses pressure change

in the product gas downstream of the product delivery valve (shown schematically in Figure 1) caused by inhalation and exhalation of the patient so that the gas delivery frequency can be adjusted accordingly. The breath detector 520 may also include a second pressure transducer that senses the storage vessel pressure which is used to drive the delivery of the product to the patient through the product delivery valve. The breath detector 520 ports directly into the manifold instead of tapping into the product line downstream, which obviates the need of additional tubing connections and reduces the risk of leakage.

[0045] Advantageously, the PSA unit 506 has many novel features which, individually and in combination, contribute to a lighter, more compact and reliable apparatus. As shown in Figure 5, the PSA unit 506 is mounted in the first compartment 300 which is thermally isolated from other heat generating components in the housing 206. Thermal isolation of the PSA unit 506 substantially prevents heat degradation of the valves 514 and other components in the unit. The PSA unit 506 is also configured with integrated gas flow passages so as to substantially eliminate the use of flexible tubing, which in turn reduces the number of potential leak points. Moreover, the PSA unit 506 is designed to operate with a single, generally planar integrated manifold mounted horizontally on one end of the columns. The single manifold design reduces the amount of space the PSA unit occupies inside the housing and also reduces potential leak points. Additionally, the PSA unit 506 is configured to directly connect to a circuit board without additional wires, which further conserves space and simplifies assembly.

[0046] Figure 6 provides a detailed view of the adsorbent bed columns 508a, 508b of the PSA unit, illustrating the novel single-ended column design briefly described above. As shown in Figure 6, the column 508a generally includes an elongated adsorbent housing 602 having an upper end 604 and a lower end 606, each defining an opening through which gas can flow in and out of the housing 602. The column 508a further includes an integrated feed tube 608 extending from the upper end 604 of the housing 602 to the lower end 606. The feed tube 608 provides a gas passageway between the manifold and the housing 602 such that gas from the manifold can be routed through the feed tube 608 into the lower end 606 of the housing 602 and vice versa. This design eliminates the need of a second manifold for directing gas into the lower end 606 of the housing 602 and allows all

flow passages in the manifold to be co-located in a single plane, which significantly reduces the number of tubing connections and potential leak points in the unit.

[0047] The feed tube 608 preferably has a relatively small internal diameter to substantially minimize head space. It is generally recognized that the feed passage in a PSA unit represents head space, which is undesirable as it penalizes system performance. In one embodiment, the feed tube 608 has an internal diameter of about 0.125 inch and the adsorbent housing 602 has a diameter of about 1.5 inch. Moreover, the adsorbent housing 602 and the feed tube 608 are preferably integrally formed in an extrusion process so as to eliminate the use of flexible tubing and reduce potential leakage. In certain embodiments, the adsorbent bed column 508a further includes a plurality of threaded mounting members 610 positioned adjacent the adsorbent housing 602 for mating with screws that attach the column 508a to the chassis and manifold. The threaded mounting members 610 are preferably co-extruded with the housing 602 and the feed tube 608 so as to simplify part construction.

[0048] As also shown in Figure 6, the adsorbent bed housing 602 contains an adsorbent material 612, an upper and a lower restraining disk 614a, 614b for inhibiting movement of the adsorbent material 612, a spring 616 that applies pressure across the upper restraining disk 614a to keep the disk 614a in position. In one embodiment, the adsorbent material 612 comprises a granular material such as zeolite that can be easily dislodged. The restraining disks 614a-b are preferably comprised of a frit material that can also serve as a filter for gross particulate, such as dislodged zeolite. Each restraining disk 614a-b has a diameter selected to form an interference fit with the internal walls of the housing 602 and has a thickness of at least about 0.2 inch, to provide some resistance to tilting of the disk, which may lead to leaks of particulate. The thickness of the disk 614a-b coupled with the nature of the frit material provide a tortuous path for particulate to travel through, which increases the effectiveness in trapping the particulate as compared to conventional paper filters. As also shown in Figure 6, the upper restraining disk 614a is pressed against the adsorbent material 612 by the spring 616. The spring 616 is preferably a wave spring configured to apply substantially uniform pressure across the surface of the upper restraining disk 614a, so as to substantially inhibit the disk from tilting.

[0049] As also shown in Figure 6, the adsorbent bed column 508a further includes annular gaskets 616a, 616b positioned adjacent to and in sealing engagement with the ends 604, 606 of the column 508a to contain the pressurized gases therein. In one embodiment, each annular gasket 616a-b further comprises an integrally formed filter portion 618a, 618b for filtering smaller particulate that cannot be captured by the restraining disks 614a-b. Preferably, the filter portion is capable of filtering particles greater than about 70-120 microns. In one embodiment, the gasket 616a-b is made of a silicone material and the filter portion 618a-b comprises a woven fabric, woven screen, or the like that is cast or molded together with the gasket. In another embodiment, the gasket 616a-b and filter portion 618a-b for all three columns of the PSA unit are injection molded as a single piece as shown in Figure 6. Preferably, the filter portion 618a-b is embedded in the gasket 616a-b so as to facilitate placement of the filter portion and ensure a reliable seal between the gasket and the filter portion. Moreover, openings 620 are formed in each gasket 616a-b to accommodate openings in the feed tubes and the threaded mounting members.

[0050] Figures 7A and 7B provide schematic illustrations of the adsorbent bed column 508a in combination with the chassis 202 and the manifold 512, showing the manners in which gas flow is directed in and out of the column 508a in accordance with the single-ended column design. As shown in Figure 7A, feed gas 702 is directed from a feed stream 704 in the manifold 512 into an upper opening 706 of the feed tube 608. The feed gas 702 travels downwardly through the tube 608 and is diverted by a divot 404a in the chassis 202 into a recess 400a underneath the lower end 606 of the adsorbent housing 602. The divot 404a, which is pre-formed in the chassis 202, advantageously serves as a lateral gas flow passageway so as to eliminate the need of any flexible tubing on the lower end of the column, which in turn simplifies assembly and reduces potential leak points. The feed gas 702 flows upwardly from the recess 400a through the lower end 606 of the housing 602 and upwardly through the adsorbent material contained in the housing 602. The adsorbent material selectively removes one or more components in the feed gas 702 in a known manner to form a product gas 708. The product gas 708 flows out of an upper end 604 of the housing 602 into a product stream 710 in the manifold 512. Figure 7B shows the manner in which purge gas is directed in and out of the column. As shown in Figure 7B, purge gas 712 from a



product stream 714 in the manifold 512 is directed through the upper end 604 of the housing 602 downwardly into the housing 602 to flush out the gas therein. The purge gas 712 exits the lower end 606 of the housing 602 and is channeled through the divot 404a. The divot 404a directs the purge gas 712 to flow into a lower opening 716 of the feed tube 608. The purge gas 712 exits the feed tube 608 through its upper opening 706 and enters a waste stream 718 in the manifold 512. As Figures 7A and 7B illustrate, the single-ended column design in conjunction with the divot formed in the chassis allow gas from a single-planed manifold to enter and exit the adsorbent housing through either the upper or lower end of the housing.

[0051] Figure 8 provides a detailed view of the integrated manifold 512 of the PSA unit. As shown in Figure 8, the integrated manifold 512 generally includes an upper plate 802 and a lower plate 804, each having grooves formed in an inner surface thereof. The grooves of the lower plate align with those of the upper plate so as to form fluid passages in the manifold 512 when the upper plate 802 is affixed to the lower plate 804. The fluid passages may include feed gas pathways, waste gas pathways, and gas pathways interconnecting the adsorbent columns. The specific pattern of the fluid passages in the manifold can vary, depending on the particular application, although the passages of the preferred embodiment correspond to the circuit of Figure 1. As also shown in Figure 8, the upper plate 802 has a feed gas inlet 812 through which pressurized air from the compressor system is directed into the manifold 512. The lower plate 804 has a waste gas outlet 814 through which exhaust gas is expelled from the manifold 512 and a plurality of openings to connect the fluid passages with the adsorbent columns. Solenoid valves 816 are mounted on an upper surface 818 of the upper plate 802 in a known manner to control the flow of fluid between the fluid passages and the PSA columns. Bores 820 are also formed in the upper and lower plates 802, 804 for receiving fasteners used to mount the plates together and onto the PSA columns. In one embodiment, the plates 802, 804 of the manifold 512 are made of a plastic material formed by injection molding and laminated together via an adhesive bond applied in a vacuum. When compared to conventional laminated manifolds that are typically constructed of machined metal plates, the integrated manifold 512 formed by injection molding is advantageously lighter and less costly to manufacture.

[0052] Figure 9 schematically illustrates a water trap system 900 integrated in the manifold 512 for removing moisture from the feed gas prior to delivery to the columns. As shown in Figure 9, the water trap system 900 generally includes an integrated water trap 902 formed in the manifold 512 and in fluid communication with a feed gas pathway 904. The water trap 902 is adapted to trap condensed water 906 in the feed gas by gravity so as to prevent the water from reaching the adsorbent bed 908. Preferably, the water trap 902 is located in a waste gas pathway 910 such that expelled waste gas carries the condensed water out through the exhaust.

[0053] In one embodiment, the water trap 902 is configured as a recess in the lower plate 804 of the manifold 512, extending downwardly from a section of the feed gas pathway 904 located in the upper plate 802. The water trap 902 is positioned at a lower elevation relative to the feed gas pathway 904 so as to substantially prevent trapped water 908 from re-entering the feed gas pathway 904. In certain embodiments, a baffle 912 is positioned in the feed gas pathway 904 to divert the feed gas flow downwardly into the water trap 902 so that the gas is required to rise upwardly to return to the feed gas pathway 904, which substantially prevents any condensed water from being carried past the water trap by the feed gas flow. As also shown in Figure 9, the water trap 902 is in line with the waste gas pathway 910 located in the lower plate 804 of the manifold 504 so that the water trap 902 can be purged by waste gas flowing through the pathway 910. In one embodiment, the water trap 902 is located in center of a three way junction formed by the airflow passages to and from the feed valve, the exhaust valve, and the connection to the top of the column.

[0054] In operation, feed gas 914 enters the manifold 512 through the feed gas inlet 812 in the upper plate 802 and is directed through a solenoid valve 816 into the feed gas pathway 904. The feed gas 914 flows across the recessed water trap 902 such that condensed water 906 in the feed gas 914 settles into the water trap 902 by gravity while the lighter components continue along the pathway 904 into the adsorbent bed 908. Preferably, the water trap 902 containing the condensed water 906 is subsequently purged by gas in the waste gas pathway 910. It will be appreciated that the integrated water trap system is not limited to the above-described embodiment. Any integrated water trap system that encompasses the general concept of forming an integrated gas flow path having a lower

region where light air flows past and moisture air condenses due to gravity are contemplated to be within the scope of the invention.

[0055] Figure 10 schematically illustrates a piloted valve system 1000 integrated in the manifold 512 for providing quick release of pressurized gas from the adsorbent columns during a PSA cycle. It is generally recognized that the efficiency of a PSA cycle benefits from fast release of the pressurized gas within the adsorbent columns during the blow down and purge steps. However, the solenoid valves controlling gas flow from the columns to the waste gas pathway are typically limited in orifice size which in turn results in restricted flow and slowed release of the gas within the columns. To increase the flow capacity, the piloted valve system 1000 shown in Figure 10 utilizes a solenoid valve to drive a much larger piloted valve that is embedded in the manifold and controls the waste gas flow to and from the columns.

[0056] As shown in Figure 10, the piloted valve system 1000 generally includes a solenoid valve 1002, an air chamber 1004 in fluid communication with the solenoid valve 1002, and a piloted valve 1006 that can be actuated by the solenoid valve 1002 through the air chamber 1004. The piloted valve 1006 preferably comprises a diaphragm 1006 positioned between the air chamber 1004 and a waste gas pathway 1008. Pressure differences between the air chamber 1004 and the waste gas pathway 1008 mechanically deflect the diaphragm 1006 to open or close the waste gas pathway 1008 to gas flow. Preferably, the diaphragm 1006 has a natural resiliency such that it is deflected away from the waste gas pathway 1008 when the air chamber 1004 is not pressurized.

[0057] In one embodiment, the diaphragm 1006 is seated in a recess 1010 that extends downwardly from an exterior surface 1012 of the upper plate 802. An insert 1014 is mounted in the recess 1010 above the diaphragm 1006 and flush with the exterior surface 1012 of the plate 802. The diaphragm 1006 has an outer rim 1016 that sealingly engages with an inner surface 1018 of the insert 1014 so as to form the air chamber 1004 as shown in Figure 10. The insert 1014 contains a plurality of openings 1020 that are in fluid communication with the air chamber 1004. The solenoid valve 1002 is mounted above the insert 1014 and controls gas flow through the openings 1020 to the air chamber 1004.

[0058] As also shown in Figure 10, the waste gas pathway 1008 is formed in the lower plate 804 of the manifold and in contact with the diaphragm 1006 through an opening 1022 formed in the inner face 808 of the upper plate 802. To close the waste gas pathway 1008 from gas flow, the diaphragm 1006 is deflected toward a baffle 1024 positioned in the waste gas pathway 1008 and sealingly engages with the baffle 1024 so as to block off a pathway 1026 between the diaphragm and the baffle. To open the waste gas pathway 1008, the diaphragm 1006 is deflected away from the baffle 1024 so as to allow gas to flow through the pathway 1026 and out the exhaust. It will be appreciated that the pathway 1026 controlled by the diaphragm 1006 provides a much large flow capacity for waste gas than the orifices in the solenoid valves.

[0059] In operation, pressurized purge gas 1028 from the adsorbent column flows into the opening 1022 in the upper plate 802 and pushes the diaphragm 1006 away from the baffle 1024 so as to open the path 1026 between the diaphragm 1006 and the baffle 1024 for gas flow. After the purge gas is released through the exhaust, a portion of the feed gas is directed into the air chamber 1004 via the solenoid valve 1002 to push the diaphragm against the baffle 1024 so as to close the path 1026 therebetween. Advantageously, the piloted valve system 100 allows waste gas to be released from the column through a much larger opening than the orifices contained in the solenoid valves and does not consume additional space as the valves are all incorporated in the manifold.

[0060] Figure 11 provides a detailed view of the components inside the second compartment 302 of the housing 206. As shown in Figure 11, the second compartment 302 generally contains an air circulation fan 1102, a battery 1104, and a compressor assembly 1106. In one embodiment, the fan 1102 comprises a blower or other device used for forcing air circulation. The battery 1104 is preferably a lithium ion battery having a rated life of at least 2 hours. In certain embodiments, the battery may also comprise a fuel cell or other transportable electric power storage device. The compressor assembly 1106 includes a compressor 1108, a driving motor 1110, and a heat exchanger 1112. In one embodiment, the compressor 1108 is preferably a non-reciprocating compressor such as a scroll compressor or a radial compressor and the motor 1110 is preferably a DC brushless motor. In certain embodiments, the compressor 1108 can also be a vacuum pump or a combination of a

vacuum pump and a compressor. The heat exchanger 1112 can be in the form of aluminum coiled tubes or other common heat exchanger designs. In one embodiment, the heat exchanger 1112 has an inlet 1114 and an outlet 1116. The inlet 1114 is in fluid communication with the compressor 1108 for receiving feed gas therefrom and the outlet 1116 is connected to the PSA unit for delivery feed gas thereto.

[0061] As also shown in Figure 11, the compressor 1108 rests on an upper surface 1118 of the compressor mount 406, which is elevated above the base 208 of the housing. The driving motor 1110 attached to the compressor 1108 extends into the opening 410 in the compressor mount 406 and remains suspended therein. Moreover, the heat exchanger 1112 is positioned above the compressor 1108 and under the fan 1102. Preferably, the fan 1102 directs an air flow against the heat exchanger 1112 to facilitate cooling of the feed gas therein. As also shown in Figure 11, the battery 1104 is mounted on the battery bail 414 via three pairs of guide rails 1120 formed on the battery and adapted to mate with the battery bail 414. The distance between the guide rails 1120 becomes progressively shorter from bottom to top, with the topmost pair forming the tightest fit with the bail 414. This facilitates mounting of the battery particularly for those with impaired dexterity. When the battery 1104 is in position, the topmost guide rails are held firmly by the bail 414 while a lower section 1130 of the battery 1104 is held firmly by the mated electrical connectors formed in the battery slot 412.

[0062] In one embodiment, a compressor restraint 1122 is connected between the compressor 1108 and the chassis 202 to secure the compressor 1108 to the housing 206. Preferably, the compressor restraint 1122 comprises an elastic tether that fastens the compressor 1108 to the chassis. Preferably, the chassis is fit with grooves for engaging with the compressor restraint. In one embodiment, the compressor restraint 1122 comprises two elongated legs 1124a, 1124b spaced apart in the middle and joined together in an upper end 1126a and a lower end 1126b. The upper end 1126a is removably attached to the compressor 1108 and the lower end 1126b removably attached to the chassis 202. Moreover, the elongated legs 1124a, 1124b preferably have preformed bends which extend away from each other. These bends can be pressed toward each other to straighten the legs and increase the overall length of the compressor restraint 1122 so as to facilitate mounting and removal of

the compressor restraint. Preferably, the compressor restraint does not substantially exert active force on the compressor assembly when the housing is in its upright position so as to reduce vibration coupling from the compressor to the chassis.

[0063] In another embodiment, a vibration damping member 1128 is interposed between the compressor mount 406 and the compressor 1108 to further reduce transfer of vibrational energy from the compressor to the housing. As shown in Figure 12, the vibration damping member 1128 comprises a grommet 1202 configured to mate with the annular compressor mount so as to provide a vibration damping mounting surface for the compressor system. Preferably, the grommet 1202 is made of a resilient silicone material such as sorbothane and configured to absorb low vibrational frequencies produced by the compressor. In one embodiment, a first set of ribs 1204 are formed along the periphery of an upper surface 1206 of the grommet 1202 and configured to absorb vibration from the compressor. In another embodiment, a second plurality of ribs 1208 are formed on an inner surface 1210 of the grommet 1202 and configured to absorb vibration from the motor. The ribs 1204, 1208 substantially reduce the amount of vibration transferred to the grommet 1202 which is in contact with the compressor mount. The compressor advantageously rests on the grommet without being pressed against the chassis during normal operations and is restrained by the compressor restraint only when the apparatus is tipped over on its side. The vibration damping member 1128 is advantageously configured to reduce transfer of vibration energy, particularly low frequency vibration, from the compressor system to the housing, thus reducing noise created by vibration of the housing.

[0064] In addition to vibration control features, the apparatus also incorporates one or more thermal management systems to provide cooling for temperature sensitive components inside the housing and facilitate heat dissipation. Figure 13 illustrates a thermal management system of one preferred embodiment adapted to provide cooling for the battery. A thermal sleeve 1302 is positioned around the battery 1104 to isolate air surrounding the battery 1104 from higher temperature air in the second compartment 302 of the housing. A lower end 1304 of the thermal sleeve 1302 is configured to mate with the battery slot 412 so as to close off the lower opening of the sleeve and form a compartment or air pocket for the battery. A cooling gas is preferably directed into the space between the thermal sleeve 1302

and the battery 1104 to facilitate dissipation of heat generated by the battery and also to insulate the battery from heat generated by other components in the housing.

[0065] In one embodiment, a conduit 1306 extends from the exhaust outlet 814 of the PSA unit 506 to an opening 1038 in the battery slot 412. The conduit 1306 directs exhaust gas 1312 from the PSA unit 506 into the space between the thermal sleeve 1302 and the battery 1104. Since the exhaust gas is typically cooler than ambient air surrounding the battery compartment, it serves as an efficient source of cooling air for the battery. The exhaust gas enters the thermal sleeve 1302 from the lower opening 1308 in the battery slot 412 and circulates out of the upper end 1310 of the thermal sleeve 1302.

[0066] As also shown in Figure 13, a circuit board 1314 is mounted horizontally on the PSA unit 506, above the valves 816 on the manifold 512. The circuit board 1314 comprises control circuitry which governs the operation of the PSA unit, alarms, power management system, and other features of the apparatus. As described above, contacts on the circuit board 1314 are in direct electrical contact with mating contacts 516 on the valves 514 of the PSA unit 506, which conserves space and eliminates the need for wiring connections. In one embodiment, the circuit board 1413 has small through-hole connectors that align with the location of valve pins to establish electrical interconnection.

[0067] As will be described in greater detail below, the circuit board 1314 is located in the path of a directed air flow inside the housing so as to facilitate heat dissipation of the circuits during operation. Moreover, although the control circuitry is substantially entirely within the first compartment 300, the circuit board 1314 extends horizontally from the first compartment 300 to the second compartment 302, substantially covering the upper openings of both compartments so as to inhibit migration of higher temperature air from the second compartment 302 into the first 300. In one embodiment, foam material is placed between the outer edges 1316 of the circuit board 1314 and the inner walls of the housing to form an air seal which further inhibits migration of air between the compartments 300, 302. In another embodiment, the circuit board 1314 is shaped to mirror the cross-sectional contour of the housing so as to ensure an effective seal between the circuit board 1314 and housing.

[0068] Figure 14 schematically illustrates a thermal management system of another preferred embodiment, which is configured to provide a continuous flow of cooling

air across the components inside the housing. As shown in Figure 14, ambient air 1402 is drawn into the housing 206 through an air inlet 1404 by the fan 1102. The air inlet 1404 is preferably located in a lower portion of the sidewall 212c adjacent the first compartment 300. The ambient air 1402 is directed to flow through an air flow passageway 1406 generally defined by the walls of the housing and the components therein. The air flow passageway 1406 is preferably a circuitous path extending from the air inlet 1404, through the first and second compartments 300, 302, to an air outlet 1408 located in a lower portion of the sidewall 212a adjacent the second compartment 302. Preferably, the ambient air is directed to flow across the first compartment, which contains temperature sensitive components, before entering the second compartment which contains heat generating components. As will be described in greater detail below, the thermal management system utilizes the air circulation fan 1102 in combination with the configuration of the housing and placement of components therein to produce a one-way flow passageway for air from inlet to outlet. As such, heated air is not re-circulated back into the system and the components are cooled by a continuous stream of external air.

[0069] In one embodiment, the air flow passageway 1406 has an upstream portion 1408 and a downstream portion 1410. The upstream portion 1408 includes a vertical path 1406a generally defined by the PSA unit 506 and the sidewall 212c of the housing 206 followed by a horizontal path 1406b generally defined by the circuit board 1314 and the upper wall 210. The downstream portion 1410 includes a vertical path 1410a generally defined by the partition 304 and the battery 1104, a horizontal path 1410b generally defined by the compressor assembly 1106 and the base 208 of the housing, and followed by another vertical path 1410c defined by the battery 1104 and the sidewall 212a. Air in the upstream portion 1408 of the passageway 1406 preferably has a lower temperature than air in the downstream portion 1420 where most heat generating components are located. Temperature sensitive components such as the valves 514 and electrical components disposed on the circuit board 1314 are advantageously disposed in the upstream portion 1408, thereby exposing the valves and components to a continuous stream of incoming cooling air, which reduces their thermal load. Preferably, the upstream portion 1408 of the air flow passageway



1406 is thermally isolated from the downstream portion 1410 by the partition 304 and the circuit board 1314 in conjunction with a directed air flow described below.

[0070] As also shown in Figure 14, the fan 112 is located in the downstream portion 1410 of the air flow passageway 1406 immediately above the compressor assembly 1106. The fan 112 generates a downward air stream directly against the compressor assembly 1106 to facilitate heat dissipation of the heat exchanger and compressor. The air stream flows past the compressor assembly 1106 through the downstream portion 1410 of the air passageway 1406 and exits the housing 206 through the air outlet 1408. The fan 1102 is advantageously positioned to focus a cooling air stream directly on the heat generating components inside the housing. Moreover, portions of the air stream warmed by the compressor assembly are not re-circulated inside the housing, which substantially minimizes increases in the ambient temperature therein and improves cooling efficiency. The air stream generated by the fan 1102 creates a negative pressure in the upstream portion of the passageway 1406, which draws ambient air through the passageway 1406 from the first compartment 300 to the second compartment 302 as shown in Figure 14. Although some turbulence of the air may occur downstream of the fan, the air path configuration permits substantially one way air flow along the path between the intake and the fan.

[0071] In certain embodiments, noise reduction features are also implemented in the apparatus. As shown in Figure 14, a series of sound absorbing baffles 1412 are positioned along the air flow pathway 1406 to reduce noise caused by the air flow inside the housing. Moreover, the air flow passageway is configured with a circuitous path so as to further abate the noise generated by the air flow. The circuitous path advantageously provides for air movement through the housing, but makes it difficult for sound to propagate or reflect off internal surfaces of the housing and make its way out of the housing.

[0072] Figure 15 schematically illustrates the manner in which intake air 1500 is processed through the components of the apparatus. As shown in Figure 15, intake air 1500 is drawn through the air intake 502, through the air filter 504 into an inlet port 1404 of the compressor 1108. Air is preferably drawn into the compressor air intake at a flow rate of no greater than about 15 slpm so as to maintain a low noise level and low power consumption throughout the system. The air is pressurized by the compressor 1108 and delivered to the

heat exchanger 1112 through the compressor outlet 1406. The pressurized air is cooled by the heat exchanger 1112 and then supplied as feed gas to the PSA unit 506. Feed gas is directed through the inlet port 812 of the PSA unit 506, into adsorbent columns 508a-b to produce a product gas in accordance with a PSA cycle, preferably the six step/two bed cycle described above. Product gas from the adsorbent columns 508a-b flows into the storage column and is delivered to the patient through an outlet port 1408 in the manifold 512 connected to the storage column. Preferably, the product gas is delivered to the patient at a flow rate of between about 150 ml/minute and 750 ml/minute and having an oxygen concentration of at least 87%, more preferably between 87%-93%.

[0073] Figure 16A shows the apparatus as fully assembled in the form of a portable oxygen concentrator unit 1600. The unit 1600, including the housing and components therein, has a combined weight of preferably no than about 10 pounds and produces a noise level of no greater than about 45 dB external to the unit. As shown in Figure 16A, an air scoop 1602 is integrally formed in the sidewall 212 c of the shell 204 adjacent the air outlet 1408 to channel air flow out of the housing 206. A similar air scoop is also formed in the sidewall adjacent the air inlet (not shown) to channel ambient air into the housing. As described above, the sidewalls 212a, c of the housing have a curved configuration so as to discourage users from resting the housing against the sidewall, which can block the air inlet or outlet.

[0074] As also shown in Figure 16A, a user interface panel 1602 containing a plurality of system controls 1604 such as flow rate and on-off switches is integrally formed in the shell 204. In some embodiments, an I/O port 1606 is preferably formed in the user interface panel 1602. The I/O port allows data transfer from the unit to be performed simply by using a complementary device such as a palm desktop assistant (PDA) or laptop computer. Moreover, an in-line filter system 1608 is also formed in the shell 204 to filter product flow in line prior to delivery to the patient. As will be described in detail below, the in-line filter system 1608 is integrated in the shell 206 of the unit so as to provide easy access to the filter without requiring opening of the shell.

[0075] As shown in Figure 16B, the in-line filter system 1608 includes an annular chamber 1610 formed in the shell 204 and a fitting 1612 that engages with the chamber 1610

from outside of the shell. The chamber 1610 has a seat portion 1612 configured to receive a disk filter 1614 and a threaded portion configured to engage with the fitting 1612. Preferably, the chamber 1610 is molded into the shell 204 and oxygen product inside the housing is ported to the chamber. In one embodiment, the disk filter 1614, preferably a 10 micron or finer filter, is held in compression in the seat portion 1612 of the chamber by the fitting 1612, which threadably engages with the chamber 1610 from outside of the shell. In another embodiment, the fitting 1612 also contains a hose barb 1618 used to connect the cannula. Advantageously, the disk filter 1614 can be serviced by simply unscrewing the fitting 1612, replacing the filter 1614, and then re-screwing the fitting 1612 without ever having to open the housing of the unit. As shown in Figure 16C, the unit 1600 also includes a removable hatch 1620 that provides simplified access to the circuit board 1314 inside the housing 206 and the internal connections to the oxygen product line and power input.

[0076] Figure 17 schematically illustrates a satellite conserver system 1700 that can be used in conjunction with the oxygen concentrator unit 1600 to deliver oxygen to users. It is generally recognized that oxygen concentrators deliver a finite rate of oxygen product which must be metered to the user through a conserving device. A conserving device is typically mounted inside the concentrator and includes a breath sensor that senses breath inhalation of the user to determine the timing and quantity of each bolus delivery. The sensitivity of the breath sensor is significant to the efficacy of the conserving device. As such, most conserving devices require that users use no longer than a 10 feet tube connected to the nasal cannula to ensure that the conserving device inside the concentrator can accurately sense the breath of the user.

[0077] The satellite conserver 1700 is configured to substantially remove the constraint imposed by the short tube requirement and allow users the freedom to move in a much larger area around the portable concentrator. As shown in Figure 17, the satellite conserver 1700 includes a small, lightweight conserving device 1702 for delivering oxygen rich product gas to users in metered amounts in a known manner in response to sensed breath. The conserver 1700 includes a breather sensor 1701 for sensing the user's breath and a delivery valve 1703 for delivering oxygen to the user. In one embodiment, the conserving device 1702 utilizes a breath rate algorithm that delivers a nearly constant amount of oxygen

per minute, regardless of the breath rate of the patient. As such, patients who take more breaths within a give time period receive the same amount of oxygen as those who take less breaths. In another embodiment, the conserving device adjusts the bolus volume based on the flow setting rather than the breathing rate. In yet another embodiment, the conserving device 1702 can be fit with a second pressure sensor, which detects the pressure in the input line from the concentrator. The delivery valve timing can be adjusted based on the sensed pressure at the end of the input line such that a higher pressure corresponds to a shorter valve open time and a lower pressure corresponds to a longer valve open time.

[0078] As also shown in Figure 17, the conserving device 1702 is adapted to be worn by the user or positioned adjacent to the user so that breath sensing functions can be performed proximate to the user even if the concentrator unit is far away. Thus, the sensitivity of the breath sensor is not compromised even if the user is far way from the unit. The satellite conserver 1700 further includes flexible tubing 1704 connecting the conserving device 1702 to the hose barb fitting 1612 on the concentrator 1600. In one embodiment, the tubing 1704 is preferably between 50 to 100 feet, which provides users a much greater radius of mobility. When the satellite conserver 1700 is in use, the breath detector mounted inside the housing of the concentrator is disabled. As also shown in Figure 17, the satellite conserver can be worn on the person by a clip 1706 attached to the conserving device 1702. The satellite conserver advantageously permits the user to move around the vicinity of the concentrator, preferably in at least a 50 to 100 feet radius, without detracting from the efficacy of the unit.

[0079] Figure 18A schematically illustrates a mobility cart 1800 configured to transport an oxygen concentrator unit for users traveling away from home. As shown in Figure 18A, the mobility cart 1800 includes a generally rectangular frame 1802 attached to a plurality of wheels 1804 so as to permit rolling movement of the frame 1802 over the ground. As also shown in Figure 18A, the frame 1802 has a support portion 1806 adapted for receiving an oxygen concentrator unit and a handle portion 1808 extending upwardly from the support portion 1806 for users to hold when moving the cart. The support portion 1806 preferably contains a compartment 1810 configured to seat the oxygen concentrator and at least two slots 1812 configured to seat and secure spare batteries. In one embodiment, a

battery bail 1814 is placed in each slot 1812 for securing the batteries in the manner described above. In another embodiment, a small recess 1816 is formed in the back of the compartment 1810 for holding the satellite conserver, spare cannulas or filter.

[0080] As also shown in Figure 18A, the mobility cart 1800 further includes an on-board power supply 1818 that is attached to the frame 1802 portion. Preferably, the power supply 1818 has an AC power input and is adapted to power charging terminals fitted in each battery slot 1812 and a terminal fitted in the compartment for charging the battery within the concentrator. In one embodiment, the cart also has an adapter plug 1820 that extends from the power supply 1818 and mates with the concentrator's DC power input jack. The power supply 1816 is preferably sufficient to power both battery chargers while simultaneously powering the concentrator unit and charging the battery mounted inside the unit. Each battery preferably has a rated life of at least 2 hours so that the user is able to enjoy continuous use of the concentrator unit for at least six hours without an external power source. In one embodiment, the power supply is cooled by a fan mounted on the frame portion 1802. In another embodiment, the frame portion has recesses through which water may drain out without damaging the parts. The cart 1800 can further comprise an integrated power cord and/or retractable power cord that is adapted to be plugged into a wall.

[0081] Figure 18B illustrates the manner in which the oxygen concentrator 1600 and spare batteries 1822 are positioned in the mobility cart. As also shown in Figure 18B, the handle 1808 has two telescoping rails that can be extended and retracted. When the handle 1808 is in the fully retracted position as shown in Figure 18B, the mobility cart 1800 preferably has a height of about 14-18 inches and can be stored in a small area such as under an airplane seat. In one embodiment, the mobility cart is structured such that the concentrator, when sitting in the cart, interfaces closely with seals positioned on the frame of the cart at the air intake and exhaust ports. As such, airflow coming into or out of the concentrator actually travels through the frame in some manner, adding extra sound attenuation by increasing the tortuosity of the flow path. Moreover, an auxiliary fan or blower mounted in the cart can also be used to circulate this air further. Advantageously, the mobility cart has integrated battery chargers and power supply incorporated in one unit so as to obviate the need for users to pack power supplies or external chargers when traveling with

their concentrator. Moreover, the cart provides a single compact unit in which all oxygen concentrator related parts can be transported, which allows users greater ease of mobility when traveling.

[0082] Although the foregoing description of certain preferred embodiments of the present invention has shown, described and pointed out the fundamental novel features of the invention, it will be understood that various omissions, substitutions, and changes in the form of the detail of the system, apparatus, and methods as illustrated as well as the uses thereof, may be made by those skilled in the art, without departing from the spirit of the invention. Consequently, the scope of the present invention should not be limited to the foregoing discussions.